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ABSTRACT: Efficacy of Compound 1080 LP Collars was studied under pen and field conditions. Coyotes poisoned themselves by attacking collared sheep and biting the collars. In 54 pen tests where 1 or 2 captive coyotes had opportunity to attack 1 collared lamb, 41 lambs were attacked and 26 collars were punctured. Of 25 different coyotes offered lambs with collars containing 5 or 10 mg sodium fluoroacetate (FAC)/ml, 23 coyotes attacked and 21 died after collars were punctured in their first (n = 17), second (n = 3), or fifth (n = 1) test. For 11 captive coyotes that punctured rubber collars, the average time to death was 217 min (range 115 to 436 min).

Collars were placed on approximately 3 percent of the sheep on 4 Idaho and 7 Montana sheep ranches. Coyotes attacked 67 uncollared and 68 collared sheep, punctured 32 collars, and may have punctured 2 other collars that were not found. Documented rates of collar puncture were 48% for all attacks on collared sheep and 64% for neck-throat attacks. Eight collars were punctured on fences, thorns or brush. All coyotes that punctured collars probably died, but only 3 dead coyotes were found. Adverse impacts on humans, domestic animals, and nontarget wildlife were not seen. The LP Collar is a safe, effective, and selective technique for removing coyotes that attack sheep.

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INTRODUCTION

Coyote (Canis latrans) predation on sheep is a major problem for many livestock producers in the United States. Common techniques to reduce predation involve repelling, excluding, or removing coyotes from sheep pastures and rangelands. The Federal-Cooperative Animal Damage Control (ADC) program[a] removes many thousands of coyotes annually by aerial shooting, trapping, and other methods. In its use of lethal methods, the ADC program seeks to reduce depredations as selectively as possible by directing control to the depredating individual or local depredating population (USFWS 1979:11).

Of all lethal coyote control methods, the Livestock Protection (LP) Collar is the ultimate in selectivity for depredating individuals. This technique exploits the coyote's habit of killing sheep by biting at the neck and throat (Connolly et al. 1976, Timm and Connolly 1977, Wade and Bowns 1982). When coyotes attack collared sheep, they usually puncture the collars and receive lethal doses of toxicant.

The LP Collar was invented by R. T. McBride (1974). McBride (unpubl. data) used Compound 1080 in livestock neck collars before 1970. His work stimulated the U.S. Fish & Wildlife Service (FWS), Denver Wildlife Research Center (DWRC), to develop the data required for Environmental Protection Agency (EPA) registration of this technique. Beginning in 1974, DWRC researchers tried and rejected several other toxicants before proceeding with 1080 (Connolly et al. 1978, Savarie and Sterner 1979, Savarie et al. 1979, Sterner 1979). Pen tests with Compound 1080 began late in 1976, and field tests of 1080 collars followed in 1978. These studies ultimately led to registration of the Sodium Fluoroacetate (Compound 1080) LP Collar in 1985 (Moore 1985).

This paper describes tests of the effectiveness of LP Collars in killing coyotes that attacked collared sheep in pens (pen tests) and on commercial sheep ranches in Idaho and Montana (field tests). In addition to the studies reported here, LP Collars have been field-tested on sheep and Angora goats in Texas (R. T. McBride, unpubl. data, Wade and Connolly 1980, Scrivner and Wade 1986), New Mexico (Littauer 1984), and Alberta (P. Merrill, unpubl. data).

METHODS

Collars and Toxicant

Our work on 1080 LP Collars began with development and evaluation of prototypes. Pen tests of polyvinylchloride (PVC) and rubber prototypes in various sizes and configurations led to adoption of the test collar. It consisted of 2 hermetically sealed, black rubber packets with neck straps for attachment to livestock. Each of the 2 packets is approximately 3.5 X 5.5 cm before filling and has capacity for 12 to 15 ml of liquid.

Field experience in 1978 showed that this small collar did not adequately cover the necks of large lambs or adult sheep. Beginning in 1979, a large collar was produced for use on livestock over 23 kg (50 lb) in body weight. Each packet of the large collar is approximately 4 X 9.5 cm before filling and has capacity for 25 to 30 ml of liquid. Both large and small collars are available with either Velcro®[b] or elastic neck straps, but all tests reported here were made with velcro-strap collars.

LP Collars contained Compound 1080® (Tull Chemical Co., Oxford, AL)[b] as the toxicant and rhodamine B dye (Eastman Kodak, Rochester, NY)[b] as a marker. Compound 1080 is a technical grade of sodium fluoroacetate (FAC) and contains ≥90% active ingredient. Throughout this paper, "Compound 1080" and "1080" refer to the technical product and "FAC" denotes the active ingredient.

[a]The Animal Damage Control program, formerly managed by the Department of the Interior, U.S. Fish and Wildlife Service, was transferred to the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, by Act of Congress on December 19, 1985.

[b]Reference to trade names and/or manufacturers is made for identification and does not imply ADC program endorsement.

Toxicant solution was prepared by dissolving 1080 and rhodamine B in deionized or distilled water. Before mixing, the percent FAC was determined by laboratory analysis so that 1080 content could be adjusted to achieve precise FAC concentrations. FAC concentrations in pen tests varied between 1.5 and 10 mg/ml. In field tests, all collars contained 10 mg/ml. Rhodamine B concentrations varied from 0.5 to 3.0 mg/ml in different tests.

Collars were filled in DWRC laboratories at Twin Falls, Idaho, or Logan, Utah. A disposable hypodermic syringe was used to inject toxicant through a 3 X 17-mm, self-sealing fill plug into each collar packet. Appropriate protective clothing was worn. Loaded collars and toxicant were stored under lock and key. Disposal of used or damaged collars, animal carcasses, and other contaminated wastes was accomplished by deep burial, or burning and burial of the ashes.

Pen Tests

Pen evaluations of Compound 1080 LP Collars proceeded through 3 phases: (1) tests of PVC and rubber prototypes to establish an effective and practical collar design; (2) testing of various FAC concentrations to determine the minimum concentration required for efficacy; and (3) confirmation of efficacy of the FAC concentration (10 mg/ml) proposed for registration in commercially produced, small and large rubber collars. Phases (1) and (2) were essentially completed by late 1977. After that date, FAC in water was tested only at a concentration of 10 mg/ml. Except for 2 tests in 1979 with PVC collars, only commercially produced rubber collars were tested after 1977.

Tests were conducted at the DWRC Predator Ecology and Behavior research facility near Logan, Utah. In each test, a collared lamb was released into a 250-m^2 (21 tests) or 1-ha (33 tests) pen with 1 or 2 coyotes. Most coyote-sheep interactions were observed from an adjacent building, and data relevant to collar efficacy were recorded on a standardized form. Times of attack, collar puncture, onset of symptoms of intoxication, and death of coyote were recorded when these events were observed. Coyotes were considered dead when respiration and the eye-blink reflex ceased. Coyotes that did not puncture collars were not exposed to toxicant, and were retested at intervals of 1 day to several weeks.

Coyotes were born at the facility and reared there by their parents or by humans. Coyotes were maintained in 2.4 m x 1.4-m, sheltered kennels of chain-link fence with concrete floors and den boxes. The maintenance ration was commercial mink feed provided daily except on Sundays, and water was available ad libitum. Prior to their use in collar tests, most coyotes had attacked and killed lambs. Lambs were either reared at the research facility or purchased locally.

Differences between mean times to death for coyotes that punctured collars of different sizes (small vs. large rubber) or different materials (rubber vs. PVC) were evaluated for statistical significance using a 2-way analysis of variance, with Duncan's multiple range test where needed to separate means (5% level of significance).

Field Tests

Compound 1080 is a restricted-use pesticide. The studies reported here were conducted under EPA experimental use permit, as authorized by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), Section 5.

Collars were used on Idaho and Montana sheep ranches where coyotes had killed 2 or more sheep within 7 days, ranch fences permitted sheep management as needed to target coyote attacks to collared sheep, and ranchers agreed in writing to cooperate. On most test ranches, other control methods had failed to stop predation and collars were used as a tool of last resort.

In earliest field tests (1978-79), collars were placed and monitored primarily by researchers. Predation controls other than collars were withdrawn from test ranches to maximize the opportunity for coyote attacks on collared sheep, and cooperating ranchers were reimbursed at market value for sheep killed. Later (1981-82), the emphasis shifted from intensive research toward practical application, and collars were used by ranchers and ADC field men in conjunction with other control methods. In these tests, ranchers were not compensated for kills.

In 1978-79, field tests were monitored by one or more ADC program researchers who attempted daily verification of the status of each collared sheep. Uncollared flocks on test ranches also were checked daily for evidence of predation. In 1981-82, monitoring was performed either by ADC field men or cooperating ranchers and the monitoring frequency was reduced to 2 or 3 visits per week. When heavy predation was experienced, however, both collared and uncollared sheep were checked daily.

Each field test began with removal of sheep from pastures where coyote depredation had recently occurred. Target flocks of 10 to 20 or more lambs with their mothers were selected from the ranch flock, collared, and returned to the original pasture. Other sheep on the ranch were held in other pastures (>2 km away, if possible) where predation was not occurring, or were penned each night for protection.

In most tests, only lambs in the target flocks were collared because coyotes seldom attacked ewes when lambs were present. When sheep of all ages were attacked, all animals in target flocks were collared. Collared animals were ear-tagged or paint-branded for identification. Warning signs were posted at logical points of entry to each pasture where collars were in use.

On each monitoring visit, observers searched for indications of predator activity such as tracks or scats, concentrations of scavenging birds, or unusual livestock behavior. Collared animals were counted and inspected (usually with binoculars) to verify that collars remained in proper position. When collared sheep were missing, intensive searches were made by observers on foot or horseback until missing sheep were located or the entire pasture had been inspected. When a collar was punctured, observers also searched for carcasses of coyotes or nontarget animals that might have been poisoned. Searches curtailed by darkness or inclement weather were resumed as soon as possible.

Dead or injured sheep were examined for evidence of the cause of death or injury. Coyote predation was distinguished from other causes of death by the presence of wounds characteristic of coyote attack, and by signs of local coyote activity (Wade and Bowns 1982). Collars on dead or injured sheep were examined to determine the number of packets punctured. Broken or damaged collars, contaminated sheep parts, and vegetation were packaged in plastic bags for disposal. Uncontaminated sheep parts were buried or hauled to a carcass dump, according to cooperating ranchers' usual practice.

As tests progressed, coyote predation frequently ceased in one pasture and started in another. Sheep were then moved as necessary to keep collared animals where coyotes seemed most likely to attack, and to protect uncollared animals. Collared sheep were kept in the field as long as coyote attacks continued or were expected. In general, collars were removed 2 to 3 weeks after predation ceased. If predation resumed, collar use also resumed when collars and personnel for monitoring were available.

At each test site, events related to predation and management of collared livestock were entered in a chronological log in narrative form. Information was sometimes recorded in pocket notebooks or on wall calendars for later transcription into the log.

RESULTS

Pen Tests

Excluding early activities to establish collar design and data collection procedures, we made 54 pen tests of LP Collars (Table 1). Coyotes attacked collared lambs in 41 (76%) of these tests. Most collared lambs (36/41 or 88%) were attacked at the neck and throat. Collars were punctured in 26 attacks, giving a puncture rate of 63% (26/41) for all attacks or 72% (26/36) for neck/throat attacks. Twelve of the 26 punctured collars had only 1 packet punctured and 14 collars had both packets punctured.

Fifteen attacks on collared lambs (15/41 or 37%) did not result in punctured collars (Table 1). Reasons for failure to puncture collars were not always apparent, but in 5 tests coyotes did not attack the neck region. In 6 other tests, coyotes bit but failed to puncture collars. One of these, a PVC collar that ruptured along a seam when bitten, was not recorded as a puncture because the collar was not penetrated by coyote teeth and the coyote did not receive a dose of toxicant. Four tests resulted in neck or throat attacks but no punctures, and observers did not determine if these collars had been bitten. Each of the 4 coyotes used in these tests punctured a collar in a subsequent test. There was no indication that coyotes deliberately avoided 1080 collars. Observers were alert to this possibility because coyotes in other tests had avoided collars that contained repugnant compounds such as sodium cyanide (Burns et al. 1984).

Five of the 54 pen tests (Table 1) were made with pairs of coyotes. One or both members of each pair attacked each collared lamb and each collar was punctured, whereas single coyotes attacked in 73% (36/49) of their tests and punctured collars on only 58% (21/36) of the lambs they attacked.

Eighty-three percent (34/41) of the lambs attacked by coyotes (Table 1) were killed, but 17% (7/41) were still alive at the end of tests. Collars were punctured on 65% (22/34) of the lambs killed and on 57% (4/7) of the wounded lambs.

Table 1. Numbers of pen tests, coyote attacks, and punctured Livestock Protection Collars containing sodium fluoroacetate (FAC) and rhodamine B in water.

Collar type[a]	Tests	Total attacks	Neck/Throat attacks	Collars punctured
Large rubber (2 × 30 ml)	14	8	5	5
Small rubber (2 × 15 ml)	13	12	12	7
Other rubber (2 × 20 ml)	4	4	4	2
(All rubber collars)	(31)	(24)	(21)	(14)
Small PVC (2 × 15 ml)	12	9	8	6
Large PVC (2 × 25 ml)[b]	6	6	5	5
1-packet PVC (1 × 40 ml)	5	2	2	1
(All PVC collars)	(23)	(17)	(15)	(12)
All collars	54	41	36	26

[a]Small rubber and large rubber collars were commercial models. Other rubber and polyvinylchloride (PVC) collars were prototypes that predated commercial models. Numbers of packets per collar × volume of each packet are given in parentheses.
[b]A 2 × 20 ml collar was used in 1 test.

Fifteen collars punctured by captive coyotes contained 10 mg FAC/ml, 4 collars contained 5 mg FAC/ml, and 7 contained lower FAC concentrations (Table 2). Every coyote (n = 19) that punctured a collar containing 5 or 10 mg FAC/ml died. Two more coyotes that did not puncture collars succumbed after they participated with other coyotes in attacks on collared lambs. Collars with FAC concentrations below 5 mg/ml were not consistently lethal to attacking coyotes. Seven such collars were punctured but only 3 coyotes died (Table 2).

Table 2. Coyote mortality resulting from punctured Livestock Protection Collars containing sodium fluoroacetate (FAC) in water.

FAC mg/ml	Collar type[a]	Collars punctured	Coyotes died	Coyotes survived
10	Large rubber (2 × 30 ml)	5	6[b]	1[b]
	Small rubber (2 × 15 ml)	7	7	0
	PVC (various sizes)	3	3	0
5	PVC (various sizes)	4	5[c]	0
4	Small PVC (2 × 15 ml)	1	0	1
3	PVC (various sizes)	3	3	0
1.5	PVC (various sizes)	3	0	5[d]
Totals		26	24	7

[a]Small rubber and large rubber collars were commercial models. Polyvinylchloride (PVC) collars were prototypes. Numbers of packets per collar x volume of each packet are given in parentheses.
[b]Two tests involved pairs of coyotes. Three of these 4 coyotes died.
[c]One test involved a pair of coyotes; both died.
[d]Two tests involved pairs of coyotes; all survived.

Times from collar puncture to death were recorded for 15 coyotes (Table 3). The mean time to death was 188 min (range 90-436 min). Symptoms of intoxication were not seen until 20 to 30 min before each coyote died.

The mean time to death for coyotes that punctured large rubber collars was 154 min, significantly shorter than the 270 min average for small collars. The mean time to death for small PVC collars (117 min) was significantly shorter than that for small rubber collars (270 min). Coyotes that punctured 2 collar packets died more quickly than those puncturing only 1 packet.

Field Tests

Our first field trial lasted only 2 days because the collars leaked badly. Six of 14 collared lambs were fatally poisoned. The collar design was changed to eliminate the cause of leakage before tests resumed. After that aborted trial which is not further reported here, tests were conducted on 4 Idaho and 7 Montana sheep ranches that varied in size from 65 to 13,000 ha (160-32,000 acres). Target flocks with collared sheep were placed in fenced pastures of 5 to 700 ha (13-1,720 acres) for periods of 5 to 156 consecutive nights. The maximum number of collars per ranch varied between 9 and 46 (Table 4).

Collar effort per year on different ranches varied from 95 to 4,865 collar nights (1 collar night = 1 collared lamb in the field for 1 night). A total of 14,283 collar nights was recorded during all 4 years of field work (Table 5). While collars were in use, coyotes attacked 68 collared and 67 uncollared sheep.

Of the 68 collared sheep attacked in field tests (Table 5), 47 were bitten at the neck or throat, 4 on the head, 11 at flanks or rear, and 6 at undetermined sites (lambs were consumed or dismembered and observers could not identify points of attack). For the 62 lambs with attack site recorded, 76% (47/62) were bitten at the neck or throat.

The 68 attacks on collared sheep resulted in 66 collars that were examined for punctures (2 missing collars apparently were carried away or cached by coyotes). Thirty-two (48%) of the 66 collars were punctured (Table 5). For collared lambs known to have been attacked with neck or throat bites, the puncture rate was 64% (30/47).

Eleven (16%) of the 68 collared lambs attacked were still alive when found. Collars had been punctured on 7 (64%) of these wounded lambs, and on 25 (45%) of the 55 dead lambs for which observers determined whether or not collars had been punctured.

Of the 67 uncollared sheep attacked while collars were in use (Table 5), 9 were in target flocks. The latter figure includes 1 lamb that had crawled through a fence to join collared sheep in an adjacent pasture and 8 ewes that had not been collared because coyotes were expected to select collared lambs in preference to ewes.

Although 32 collars were punctured by coyotes in our field tests (Table 5), only 3 carcasses were found of coyotes believed to have been poisoned by collars. They were recovered approximately 0.6, 1.2, and 1.2 km (0.4 to 0.75 miles) away from points where coyotes had attacked collared lambs. No other poisoned animals were found and no adverse impacts on nontarget species were detected.

Eight collars were punctured on fence wire, brush, or thorns (Table 5). In addition to the leaking collars mentioned previously, small amounts (2 to 5 ml per collar) of toxicant seeped out of 30 collars. Seepage resulted either from collar defects or from use of an excessively large (16-gauge) syringe needle to fill collars. These problems were corrected by improved quality control during collar manufacture, and by using only small (21-gauge) needles to fill collars.

DISCUSSION

Sheep producers and predator trappers have long known that coyotes typically attack sheep with neck or throat bites. Livestock protection devices to exploit this behavior were invented many years ago. However, the LP Collar is the first practical method that causes coyotes to kill themselves when they attack livestock. In addition, only this method is demonstrably selective for individual coyotes that prey on livestock.

Since efficacy of the collar depends on coyotes making neck-throat attacks, it is important that coyotes do not deviate from normal attack behavior when collars are present. Field studies unrelated to LP Collars found that the proportion of coyote-killed sheep attacked at the neck or throat (i.e., exhibiting neck-throat wounds) was 82% in Idaho (Nass 1977) and 74% in Montana (O'Gara et al. 1983). Our results showed that the fraction of coyote attacks directed to the neck and throat of collared sheep was 88% in pen tests and 76% in field tests. Therefore, it appears that Compound 1080 LP Collars do not cause coyotes to alter their attack pattern.

Collar efficacy depends not only on the frequency of neck-throat attacks, but also on the frequency of punctures when neck-throat attacks are made. As shown above, the frequency of neck-throat attacks varied between 74 and 88% in 4 different data sets. The frequency of punctures when coyotes made neck-throat attacks on collared sheep was 64% (field tests) to 72% (pen tests). The net result was that coyotes punctured collars in 48% (field) to 63% (pen) of all attacks on collared sheep. Other studies have yielded puncture rates of 83% with Angora goats in Texas (Wade and Connolly 1980) and 50% with sheep in New Mexico (Littauer 1984).

The 50% puncture rate in New Mexico is essentially the same as our 48% rate from Idaho and Montana. Another similarity of the 2 studies is that both were learning experiences for the investigators. Collars occasionally were positioned on lambs improperly, and small collars sometimes were used on large sheep that should have had large collars. We believe that experienced users would achieve higher puncture rates.

The LP Collar may be more efficacious against problem coyotes than recorded puncture rates imply. Our pen tests yielded an overall puncture rate of 63%, yet 91% (21/23) of the coyotes that participated in attacks on lambs with collars containing 5 to 10 mg FAC/ml were killed. The reason for this seeming inconsistency is that some coyotes killed more than 1 lamb before they punctured a collar. Twenty coyotes died in their first (n = 17) or second (n = 3) attack, but one old animal with worn teeth did not die until its fifth test. All 5 collars were bitten but the first 4 were not punctured. Pen tests with other toxicants likewise documented that coyotes would attack collared sheep repeatedly until they punctured a collar and were killed (Burns et al. 1984). We conclude that Compound 1080 LP Collars will take most coyotes that habitually prey upon sheep where collars are in use.

Table 3. Mean times to death for captive coyotes that punctured Compound 1080 Livestock Protection Collars.

Collar type[a]	Packets punctured (N)	Coyotes (N)	Time to Death (Min) Mean[b]	Range	S.E.
Small rubber (2 × 15 ml)	1 or 2	6	270_y	195-436	38
	(1)	(2)	(374)	(311-436)	(62)
	(2)	(4)	(218)	(195-266)	(16)
Large rubber (2 × 30 ml)	1 or 2	5	154_x	115-211	18
	(1)	(2)	(175)	(139-211)	(36)
	(2)	(3)	(140)	(115-179)	(20)
PVC (all sizes)	1 or 2	4	108	90-144	12
(2 × 15 ml)[c]	(1 or 2)	(2)	(117_x)	(90-144)	(27)
(2 × 25 ml)	(1)	(2)	(100_x)	(95-105)	(5)
All rubber collars	1 or 2	11	217	115-436	28
All collars	1 or 2	15	188	90-436	24

[a]Rubber collars were commercial production models; polyvinylchloride (PVC) collars were prototypes. Numbers in parentheses indicate number of packets per collar x volume of each packet.
[b]Means with different subscripts differ significantly (5% level). Statistical analysis was limited to the 4 means with subscripts.
[c]One PVC collar contained 5 mg FAC/ml. All other collars in this tabulation contained 10 mg FAC/ml.

Table 4. Area, sheep numbers, and LP Collar use data for selected Idaho and Montana sheep ranches, 1978-1982.

Year	Ranch	Ranch area (ha)	Sheep[d] (N)	Area of test[a] pasture(s) (ha)	Target[b] sheep (N)	Collars[b] used (N)	Duration of[c] collar use (nights)
1978	ID:H & L[e]	570	1040	6-65	55	36	19, 12, 26, 46
	ID:W	370	630	32	59	19	5
	ID:M	300	420	49	54	26	7
	MT:R	65	1050	12	50	28	5, 20
	MT:B & C[e]	680	1500	16-65	52	46	73
1979	ID:H	130	670	16	51	22	15, 6, 13, 52
	MT:R	65	1200	12	40	20	5, 15
1981	ID:H	130	760	16	56	41	156
	MT:V	700	500	130	28	14	63
1982[f]	ID:H	130	880	5-23	23	23	76, 24, 22
	MT:H	3600	1350	400	28	14	41
	MT:W	1600	1150	81	509	9	14
	MT:N	13000	300	700	10	9	35

[a]Where collars were used in more than one pasture, areas of smallest and largest test pastures are given.
[b]Target flocks usually consisted of uncollared ewes and collared lambs. Target flock sizes and numbers of collars varied from day to day; figures shown are the largest numbers in the field on any one day.
[c]Collars were used for as many as four test periods per ranch. Numbers indicate length (nights) of each test period. Intervals between test periods varied between 4 and 80 days.
[d]Approximate number of ewes plus lambs.
[e]Test site consisted of two adjacent ranches.
[f]Includes five days of January 1983 on ID:H site.

The single most important factor in effective use of LP Collars is targeting; that is, directing coyote predation to collared livestock. Little information on targeting strategies has been published, although Gluesing (1982) suggested that low social status of newly introduced lambs acted to position them on the edge of flocks where they would be highly susceptible to predation. We did not test this approach. In our studies, targeting was attempted by placing collared sheep where coyote predation had occurred while uncollared sheep were penned at night or moved away. The resulting 67 coyote attacks on uncollared sheep and 68 on collared sheep while collars were in use indicate at least partial targeting success, since only about 3% of the sheep on test ranches were collared.

If targeting was 100% successful, no uncollared sheep would be attacked while collared sheep were available, but this ideal goal is unlikely to be realized. In our first year of field tests (1978), about 44% (36/82) of the sheep attacked by coyotes were collared (Table 5). By 1982, this figure had increased to 64% (14/22). We believe that our targeting effectiveness improved with experience. It remains to be seen whether effective targeting can be achieved with the method proposed by Gluesing (1982), or by other strategies yet to be developed.

At least 32 collars were punctured by coyotes in our field tests, yet we found only 3 carcasses of coyotes thought to have been killed by collars. We had expected to find few coyotes because of the long latent period between collar puncture and onset of symptoms of intoxication. Despite the low recovery of coyote carcasses in the field, pen tests indicated 100% mortality for coyotes that punctured collars containing 10 mg FAC/ml. We assume that the mortality rate for wild coyotes was equally high.

One aspect of collar efficacy that we did not measure directly is the amount of toxicant delivered to coyotes. However, it is reasonable to think that doses would vary in proportion to the amount of toxicant in packets and the number of packets punctured. Our data showed that coyotes puncturing large collars died in an average of 154 min. With small collars, the average time to death was 270 min. Similarly, times to death tended to be shorter when both packets were punctured regardless of collar size. Time to

Table 5. Numbers of LP Collar use nights, coyote attacks on sheep while collars were used, and collars punctured, broken accidentally, or lost on Idaho and Montana sheep ranches, 1978-82.

Year	Ranch	Collar nights (N)	Coyote Attacks: Uncollared sheep (N)	Coyote Attacks: Collared sheep (N)	Collars punctured by coyote (N)	Collars broken accidentally (N)	Collars lost (N)
1978	ID:H & L[a]	1799	22[b]	13	10	0	0
	ID:W	95	0	0	0	0	0
	ID:M	182	0	0	0	1	0
	MT:R	398	1	9	2	0	0
	MT:B & C[a]	1759	23	14	7	1	0
1979	ID:H	1466	3[c]	3	1[d]	0	1
	MT:R	280	1	0	0	1	0
1981	ID:H	4865	9[b]	15	6[d]	3	1
	MT:V	882	0	0	0	0	0
1982	ID:H	1702	4	7	3	0	0
	MT:H	446	4[e]	6	3	2	0
	MT:W	126	0	0	0	0	0
	MT:N	283	0	1	0	0	0
Totals =		14283	67	68	32[f]	8	2

[a] Test site consisted of two adjacent ranches.
[b] Includes 3 uncollared ewes in target flock.
[c] Includes 2 uncollared ewes in target flock.
[d] Another collar was missing from remains of a coyote-killed lamb, so observers could not determine if it had been punctured.
[e] Includes 1 uncollared lamb in target flock.
[f] Nine collars had both packets punctured; 23 had 1 packet punctured.

death varies inversely with Compound 1080 doses in rabbits (Chenoweth 1949), cattle (Robison 1970), and probably in coyotes. If so, our data confirm that coyotes receive larger doses from large collars, and from puncturing 2 rather than 1 collar packet.

Although each captive coyote that punctured a 10-mg FAC/ml collar died, the relatively long times to death for coyotes that punctured only 1 small collar packet indicate that such coyotes received low doses. PVC collars containing 5-mg FAC/ml were lethal to all coyotes that punctured them, and the shorter times to death indicate that PVC collars delivered more toxicant than did rubber collars. For these reasons, we recommended that the FAC concentration approved for use in rubber collars be not less than 10 mg/ml.

In our experience, LP Collars appeared to pose minimal hazard to humans, domestic animals, and nontarget wildlife. But if we are correct in assuming that many coyotes killed in the field were not found, nontarget animals also could have been killed but not found. The delayed mode of action of Compound 1080 precluded adequate documentation of animal mortalities under field conditions with the procedures we employed, so our efficacy studies were supplemented by pen and laboratory studies of nontarget hazards. The hazards were minimal. Unpublished reports are available from the authors.

We conclude that LP Collars are safe, selective, and practical in removing coyotes that attack sheep. As explained previously, the key to success with this technique is effective targeting of coyote predation to collared sheep. Rapid evolution of targeting strategies may occur as collars become more widely available to livestock producers and ADC specialists.

Coyote damage control, particularly by methods involving Compound 1080, is controversial. EPA registration of the LP Collar was difficult to achieve. FWS applied for registration in September 1981, but only after extended, formal proceedings (Gorsuch 1981, Johnson 1984, Sherman 1985) did EPA grant a conditional registration in July 1985 (Moore 1985). Additional actions and approvals were needed before collars could be used by ranchers or ADC specialists. As of March 1990, five states (Texas, New Mexico, Montana, Wyoming, and South Dakota) have established EPA-approved training and monitoring programs to allow LP Collar use by state-certified applicators.

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